Asymmetry Analysis and Results

- The 2004 commissioning run measured asymmetries for a variety of targets to:
  - test the operation of detector array and other equipment
  - measure false asymmetries from materials in the beam, other than hydrogen.

- We measured asymmetries in Al, Cu, Cl, In, ^{6}Li, and ^{10}B.

- Based on the expected gamma rate in the detectors for the hydrogen, as compared to the background rate from these other materials, the asymmetries had to be measured to a certain accuracy.

Analysis Procedure

$$Y \propto 1 + A_{\gamma}(G\,P_n\,E\,S)$$

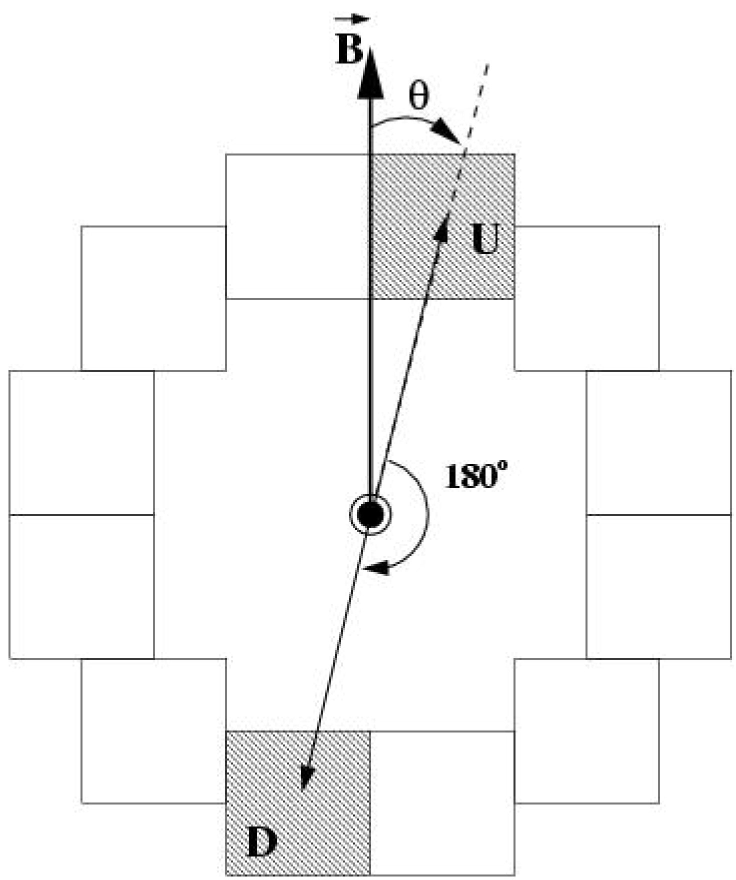
$$A_{\gamma} = \frac{A_{raw}}{P_n\,G\,E\,S} \pm \frac{\sigma_{raw}}{P_n\,|G|\,E\,S}$$

A separate A_{raw} is the measured and calculated for each detector pair and time bin, using eight consecutive macro pulses with a valid 8-step spin sequence.

$$A_{raw}(t_i) = \frac{Y_{U,\uparrow} - Y_{D,\uparrow} - Y_{U,\downarrow} + Y_{D,\downarrow}}{Y_{U,\uparrow} + Y_{D,\uparrow} + Y_{U,\downarrow} + Y_{D,\downarrow}}$$

$$\sigma_{raw}(t_i) \propto \frac{1}{\sqrt{Y_{U,\uparrow} + Y_{D,\uparrow} + Y_{U,\downarrow} + Y_{D,\downarrow}}}$$

The raw asymmetry is measured simultaneously for each detector pair to filter pulse to pulse intensity fluctuations and for a valid sequence of eight pulses to suppress detector gain drifts up to second order.



A total physics asymmetry is calculated for each detector pair and 8-step sequence from an error weighted average over the time of flight range from 12-34 ms.

$$A_{\gamma,\,pair} = \frac{\sum \frac{A_\gamma(t_i)}{\sigma_\gamma^2(t_i)}}{\sum \frac{1}{\sigma_\gamma^2(t_i)}} \pm \frac{1}{\sqrt{\sum \frac{1}{\sigma_\gamma^2(t_i)}}}$$

This is a separate and complete asymmetry measurement.

The 24 detector pairs in the array are then combined in another error weighted average to form the final asymmetry for one 8-step sequence.

Histograms are formed for the 24 pair 8-step asymmetries and the combined array 8-step asymmetry.

Correction Factors

Beam Polarization:

T_o = unpolarized beam M2/M1 transmission
T_n = polarized beam M2/M1 transmission

$$P_n = \sqrt{1 - \left(\frac{T_o}{T_p}\right)^2}$$ Neutron beam polarization

T_n and P_n are calculated on a run by run basis for each time bin (neutron energy).

The polarizer ^{3}He polarization is extracted from this by fitting tanh ($nl\sigma P$) to P_n .

$\sigma_{^3He} = 1\,\%$, $\sigma_{Pn} = 1 - 5\ \%$ from 2 – 15 meV

Spin Flipper Efficiency :

Runs were taken with a RFSF AWG amplitude setting of 850 mV and 19.165 A holding field coil current.

Efficiency peak is at 780 mV and 19.165 A, on axis.

Efficiency was taken to be 95% +- 0.05%.

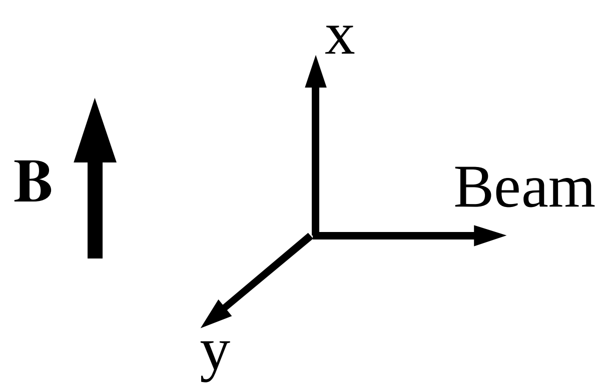
Depolarizing Due To Spin Flip Scattering:

	$\dfrac{2/3\,\sigma_{inc}}{\sigma_{tot}}$	S
Al	3.00E-003	1
Cu	2.00E-002	0.92
Cl	7.00E-002	0.92
In	2.00E-003	1
Li	3.50E-004	1
B	5.00E-004	1

Geometry Factor:

Issues related due to detector and target finite size:

- Where, in the target, will neutrons capture?
- What direction does an emitted gamma ray have and which detector(s) does it intersect?
- What is the gamma ray's angle with respect to the holding field given the detector(s) it intersected?
- How much energy will the gamma ray deposit in each detector it intersects?



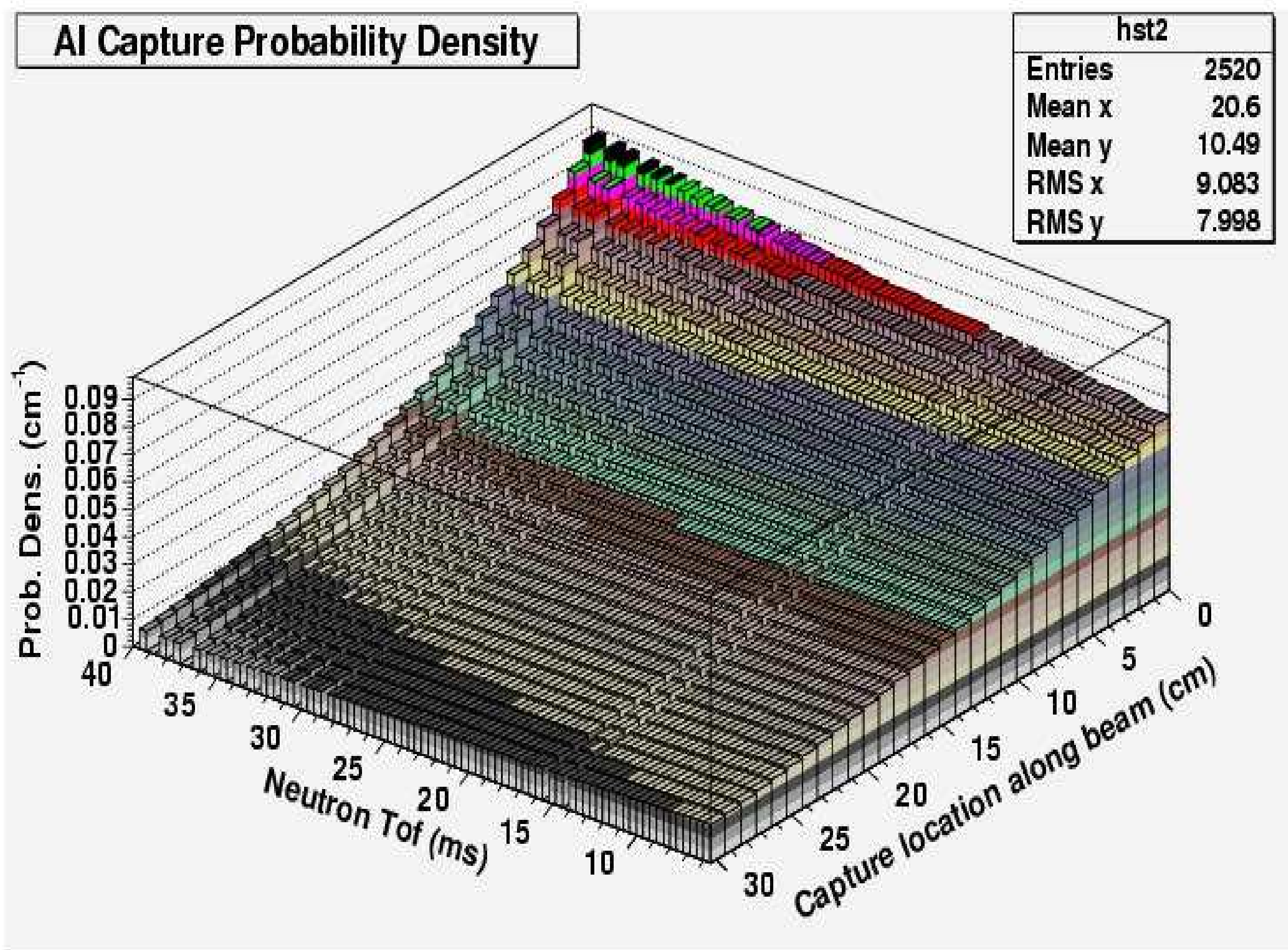
Calculation of the geometry factor by uniformely sampling the target and looking at all gamma trajectories emitted into 4π for each source point.

$$G \equiv \langle \cos(\theta) \rangle = \frac{\int_0^{2\pi} d^3x \int_0^{2\pi} d\phi \int_0^{\pi} d\theta \sin(\theta) \cos(\phi) f(\theta, \phi, z) \epsilon(z)}{\int_0^{2\pi} d^3x \int_0^{2\pi} d\phi \int_0^{\pi} d\theta\, f(\theta, \phi, z) \epsilon(z)}$$

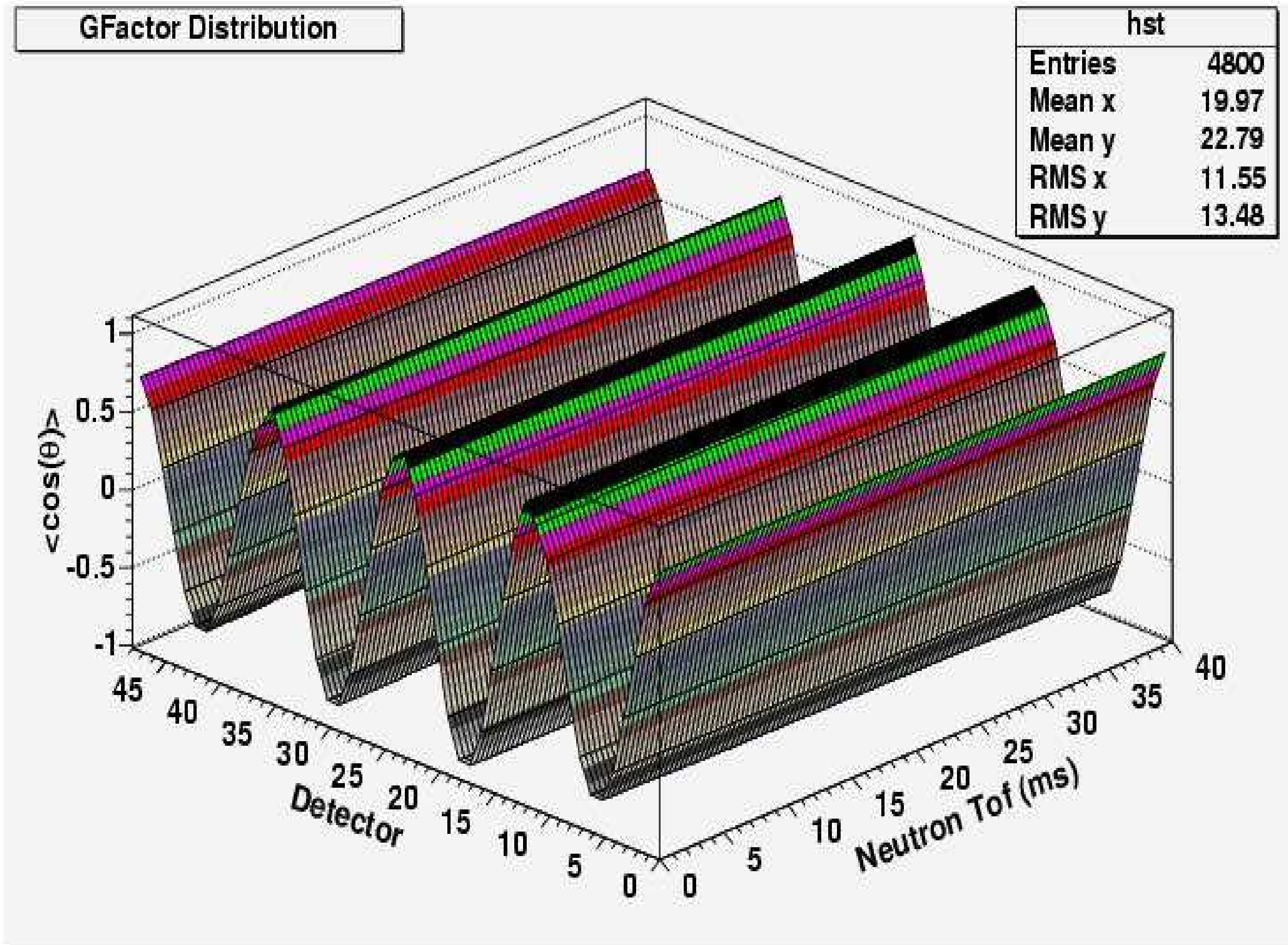
The energy deposited by a given gamma ray in a specific detector depends on the angle of the detector with respect to the vertical and the gamma source point but is modeled by a simple attenuation coefficient .

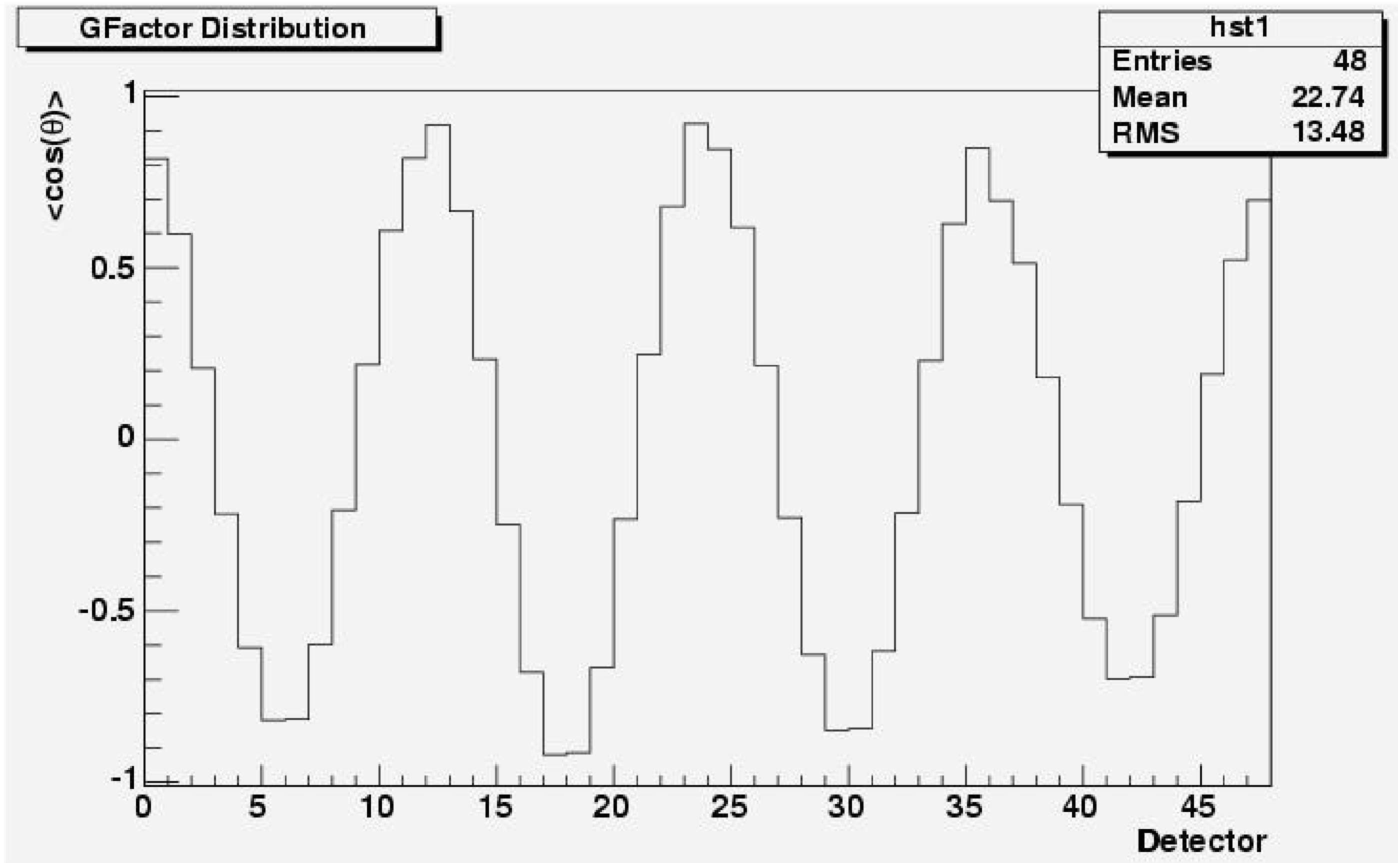
$$f(\theta, \phi, z) = \int d^3x'\, I_\gamma \left(1 - e^{-0.227\, d(\theta, \phi, z, x', y', z')}\right)$$

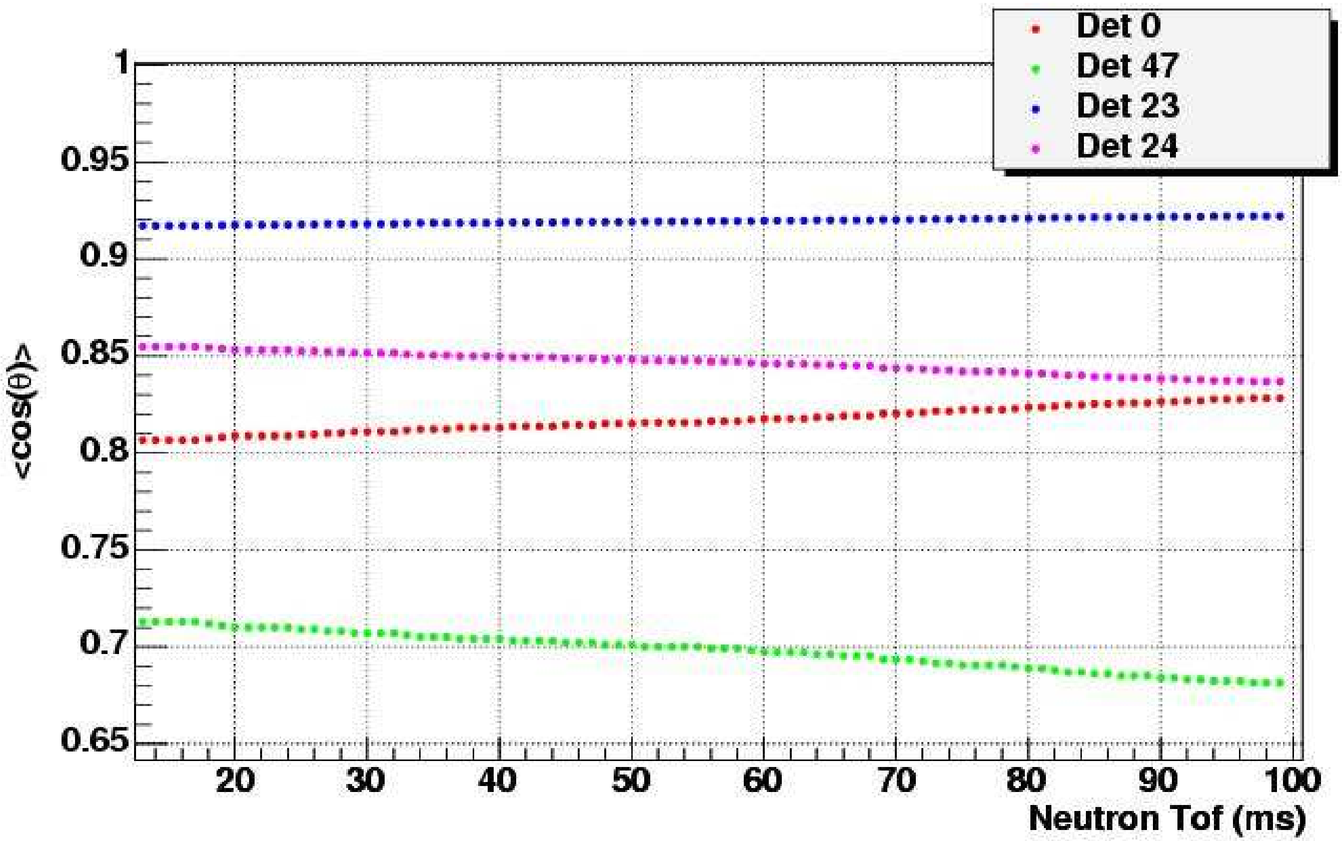
Monte Carlo calculation to establish capture distribution:



$$\epsilon(z) = \int_{z_i}^{z_f} \frac{\lambda_t e^{-\lambda_t z}}{1 - e^{-\lambda_t (30)}} dz$$


GFactor Distribution
hst
Entries 4800
Mean x 19.97
Mean y 22.79
RMS x 11.55
RMS y 13.48
<cos(θ)>
1
0.5
0
-0.5
-1
45
40
35
30
25
20
15
10
5
0
Detector
0
5
10
15
20
25
30
35
40
Neutron Tof (ms)


GFactor Distribution
hst1
Entries 48
Mean 22.74
RMS 13.48
<cos(θ)>
1
0.5
0
-0.5
-1
0
5
10
15
20
25
30
35
40
45
Detector



Det 0
Det 47
Det 23
Det 24
<cos(θ)>
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
20
30
40
50
60
70
80
90
100
Neutron Tof (ms)

Detector Gain Differences:

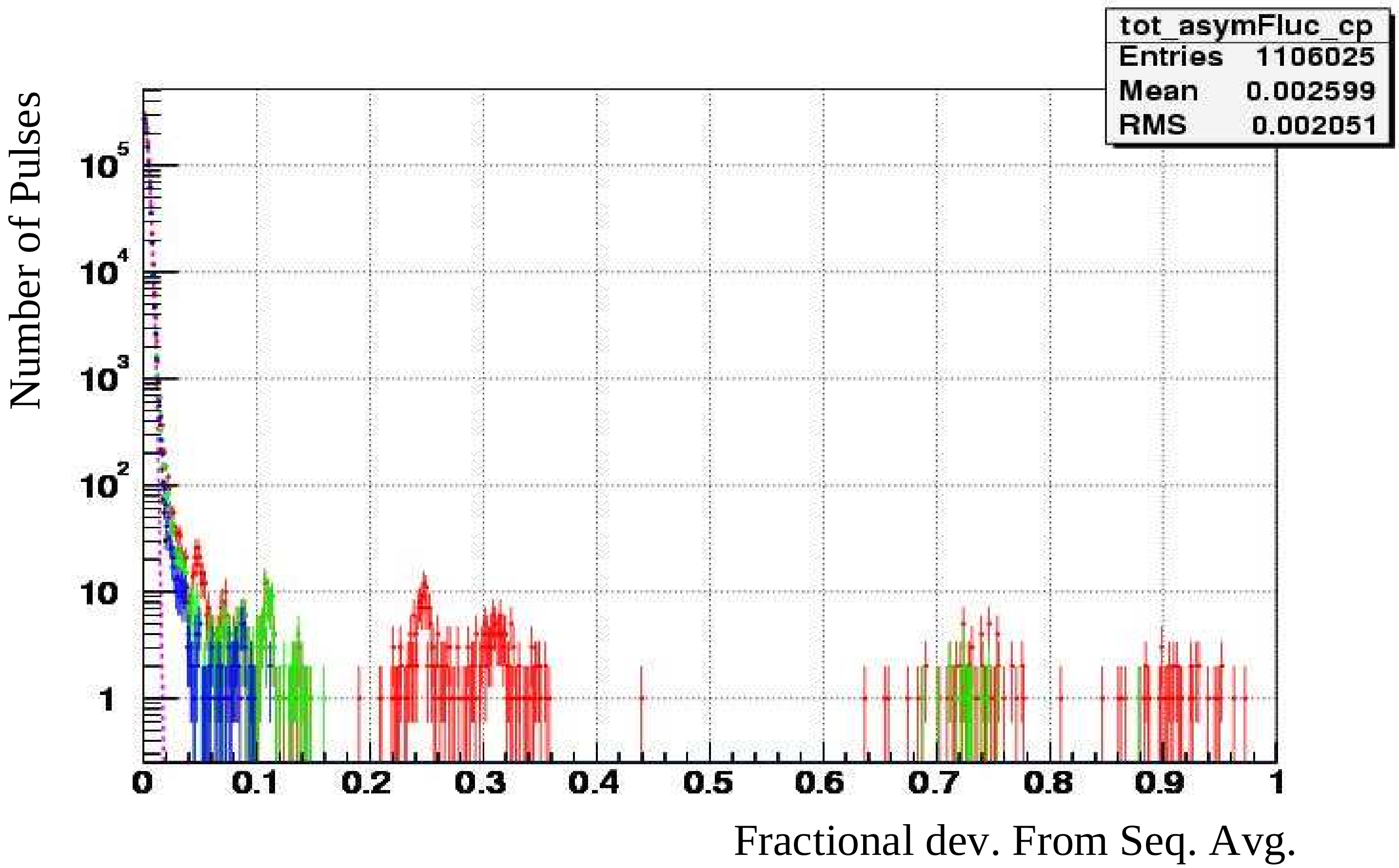
The difference between the signal levels of the two detectors in each detector pair are measured for each time bin, in the first pulse of an 8-step sequence.

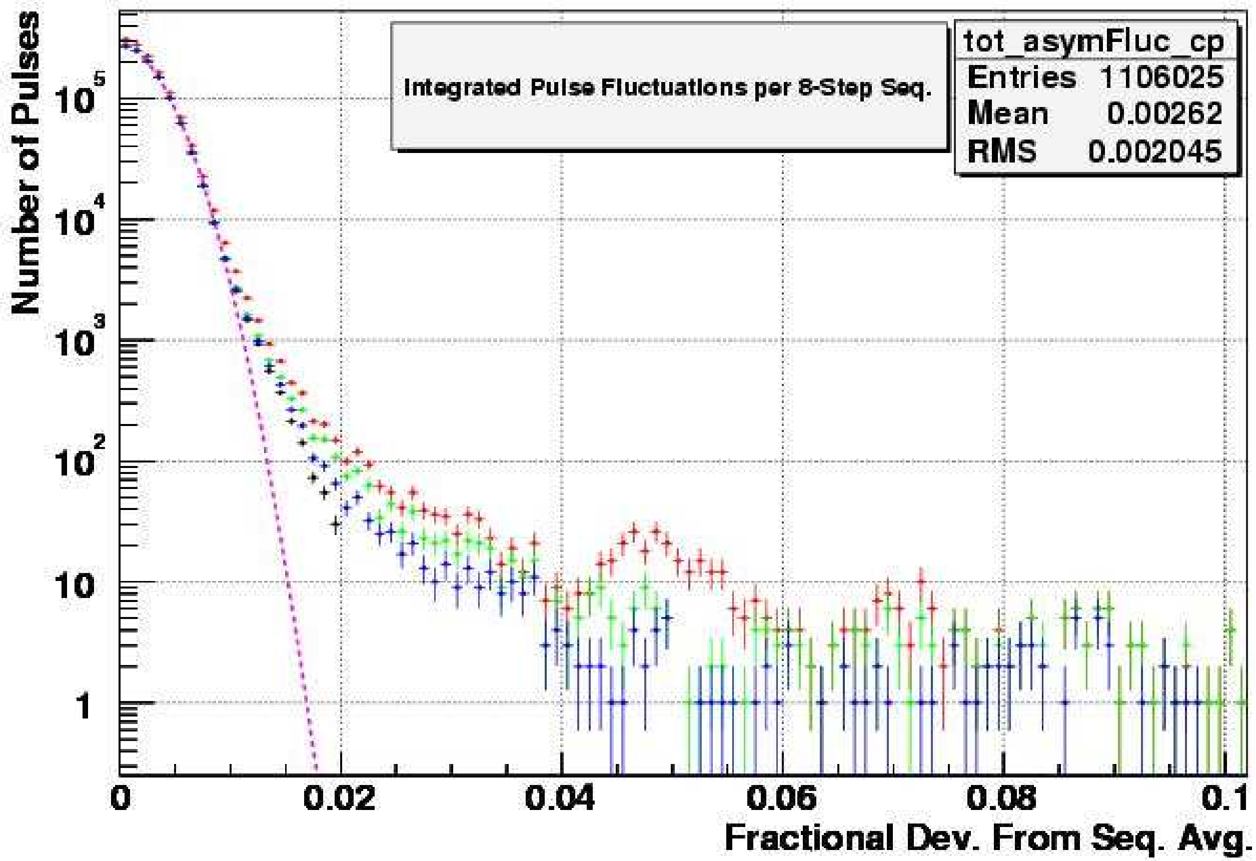
This is used to establish the relative detector gain for the pair.

$$A_{raw}(t_i) = \frac{Y_{U,\uparrow} - \dfrac{Y_U(0)}{Y_D(0)} Y_{D,\uparrow} - Y_{U,\downarrow} + \dfrac{Y_U(0)}{Y_D(0)} Y_{D,\downarrow}}{Y_{U,\uparrow} + \dfrac{Y_U(0)}{Y_D(0)} Y_{D,\uparrow} + Y_{U,\downarrow} + \dfrac{Y_U(0)}{Y_D(0)} Y_{D,\downarrow}}$$

Cuts

$$S_p \equiv \int_0^{40} dt\, S_p(t) \qquad \overline{S} \equiv \frac{1}{8}\sum_{p=1}^{8} S_p \qquad \left|1 - \frac{S_p}{\overline{S}}\right|$$




Integrated Pulse Fluctuations per 8-Step Seq.
tot_asymFluc_cp
Entries 1106025
Mean 0.00262
RMS 0.002045
Number of Pulses
10^5
10^4
10^3
10^2
10
1
0
0.02
0.04
0.06
0.08
0.1
Fractional Dev. From Seq. Avg.

Errors

Errors on the physics asymmetry are mostly statistical.

Actually,

$$A_\gamma = \frac{A_{raw} - A_{noise} - A_{backgr}}{P_n\, G\, E\, S}$$

Statistical

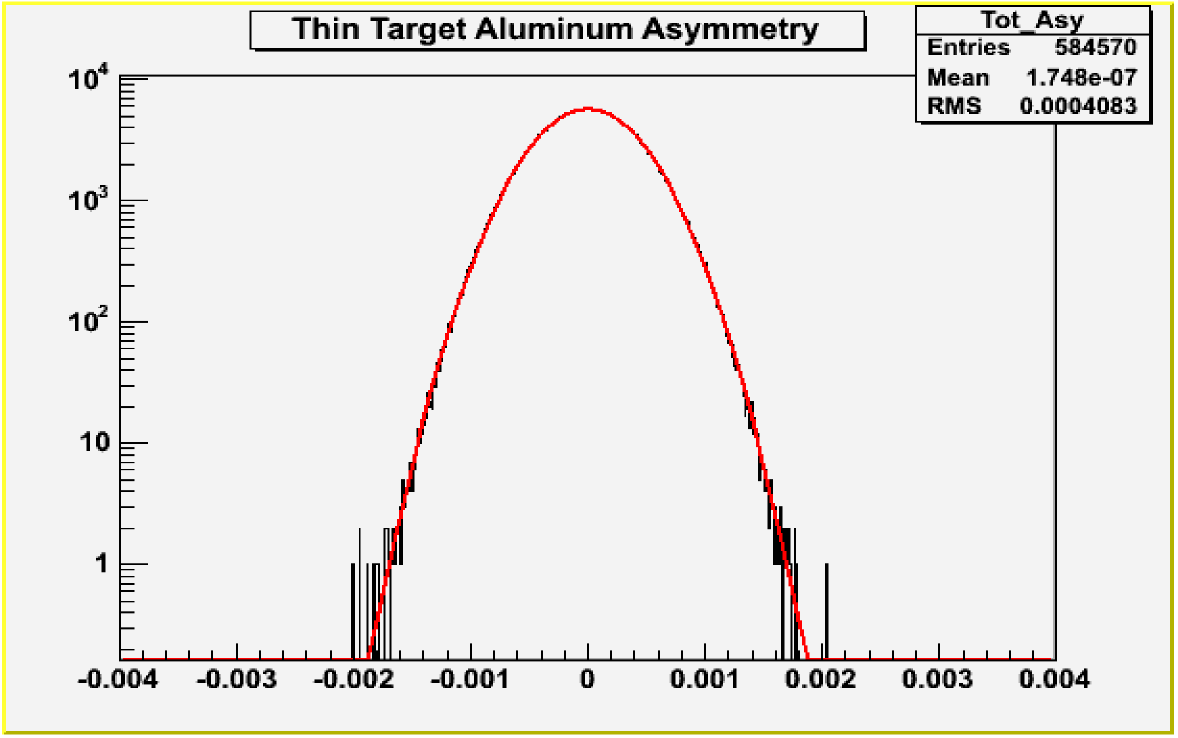
$$\sigma_\gamma = \sqrt{\left(1 - \frac{I_b + I_n}{I_s}\right)\sigma^2_{s+b} + \left(\frac{I_b}{I_s}\right)\sigma^2_b + \left(\frac{I_n}{I_s}\right)\sigma^2_n}$$

Systematic

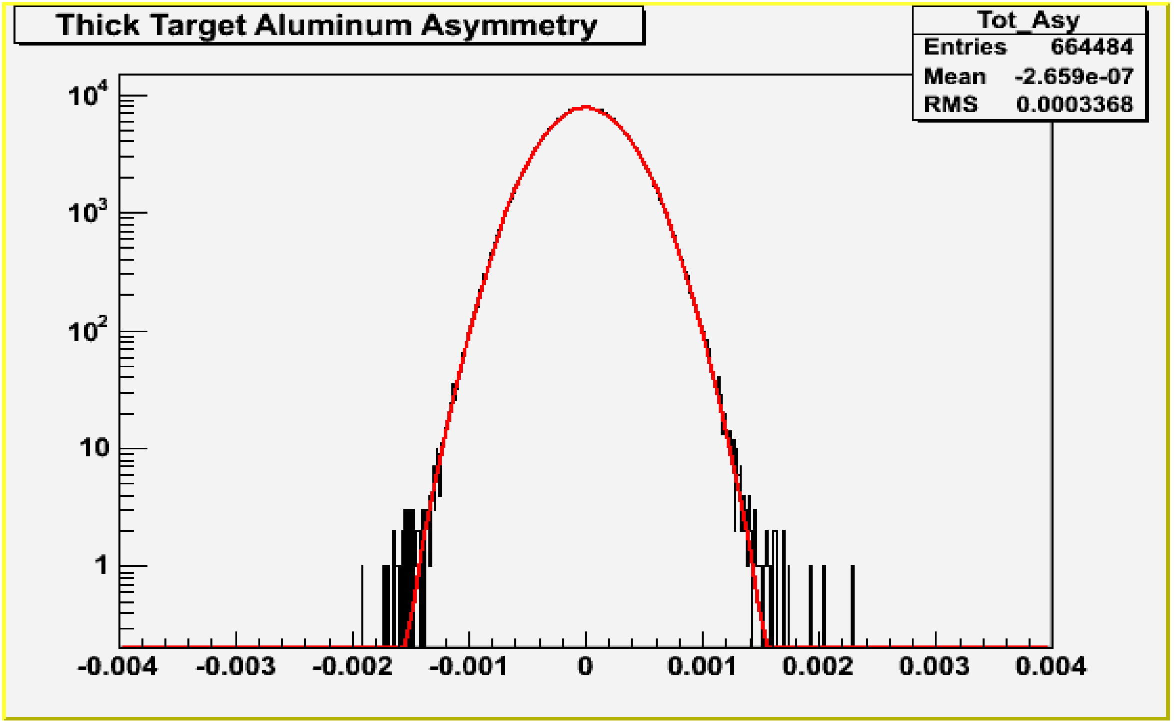
$$\sigma_\gamma = A_\gamma \sqrt{\left(\frac{\sigma_{Pn}}{P_n}\right)^2 + \left(\frac{\sigma_G}{G}\right)^2 + \left(\frac{\sigma_E}{E}\right)^2 + \left(\frac{\sigma_S}{S}\right)^2}$$

2% ? 5% ?

Asymmetry Results



$$A_\gamma = (2 \pm 5) \times 10^{-07}$$



$$A_\gamma = (-3 \pm 4) \times 10^{-07}$$

	Achieved Error	Error needed for $5x10^{-8}$ measurement
Cl	$A_\gamma = (19.4 \pm 2.0) \times 10^{-06}$	
Al	$A_\gamma = (-0.02 \pm 3.1) \times 10^{-07}$	$\pm 2.5 \times 10^{-07}$
Cu	$A_\gamma = (1.2 \pm 2.5) \times 10^{-06}$	$\pm 2.5 \times 10^{-06}$
In	$A_\gamma = (-3.2 \pm 2.3) \times 10^{-06}$	$\pm 9 \times 10^{-06}$
B	$A_\gamma = (1.3 \pm 2.3) \times 10^{-06}$	$\pm 2.5 \times 10^{-06}$

Aluminum as Background to Hydrogen Data

Based on Greg's Monte Carlo, we expect 5×10^7 γ's / pulse into the entire array, when running with hydrogen, at 100 μA.

This means we have ~3.6 V (Average) in each detector at 120 μA. The 2004 Aluminum signal (at 120 μA) ~ 1 V for the thin target and ~1.5 V for the thick target.

For the thin target we had about 5 times as much aluminum in the beam compared to running with the hydrogen target. With the thick target we had 15 times as much material.

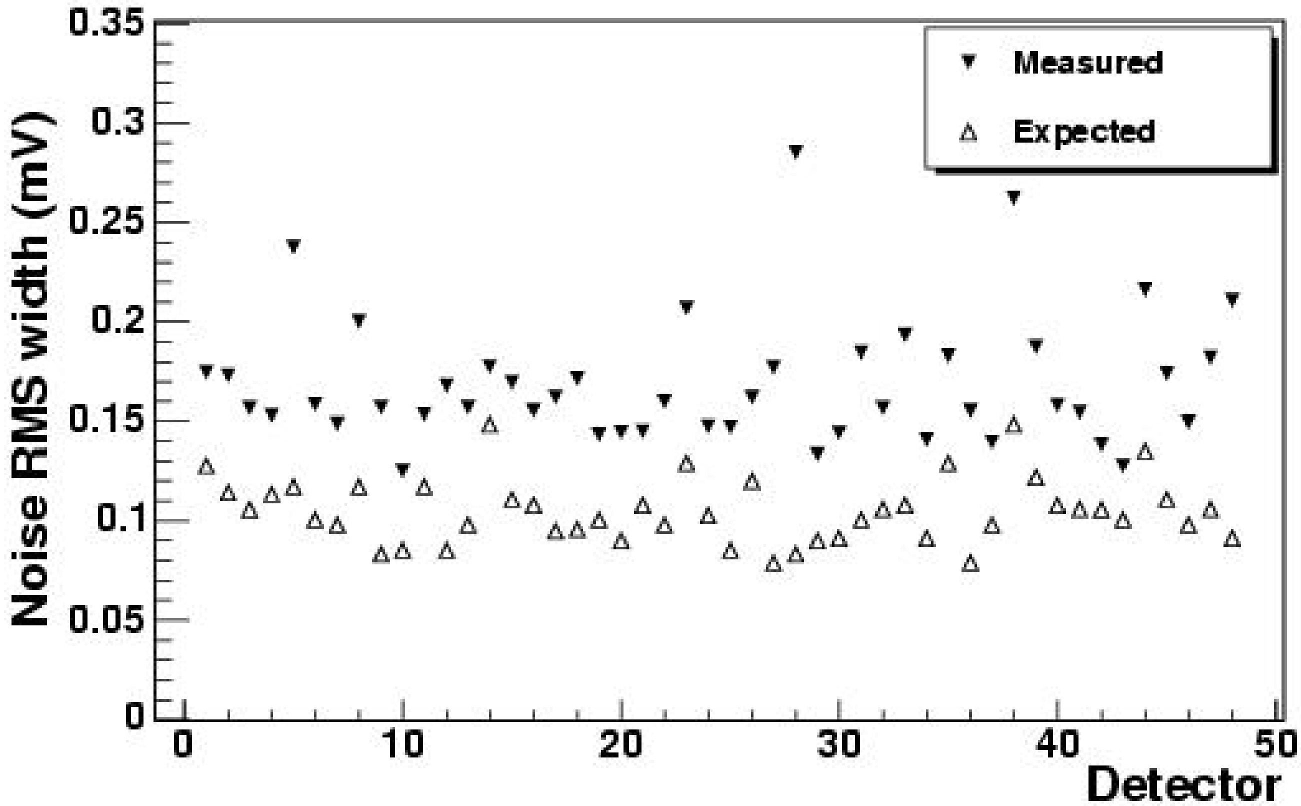
We therefore expect an upper limit of about 7% background when running with the hydrogen target.

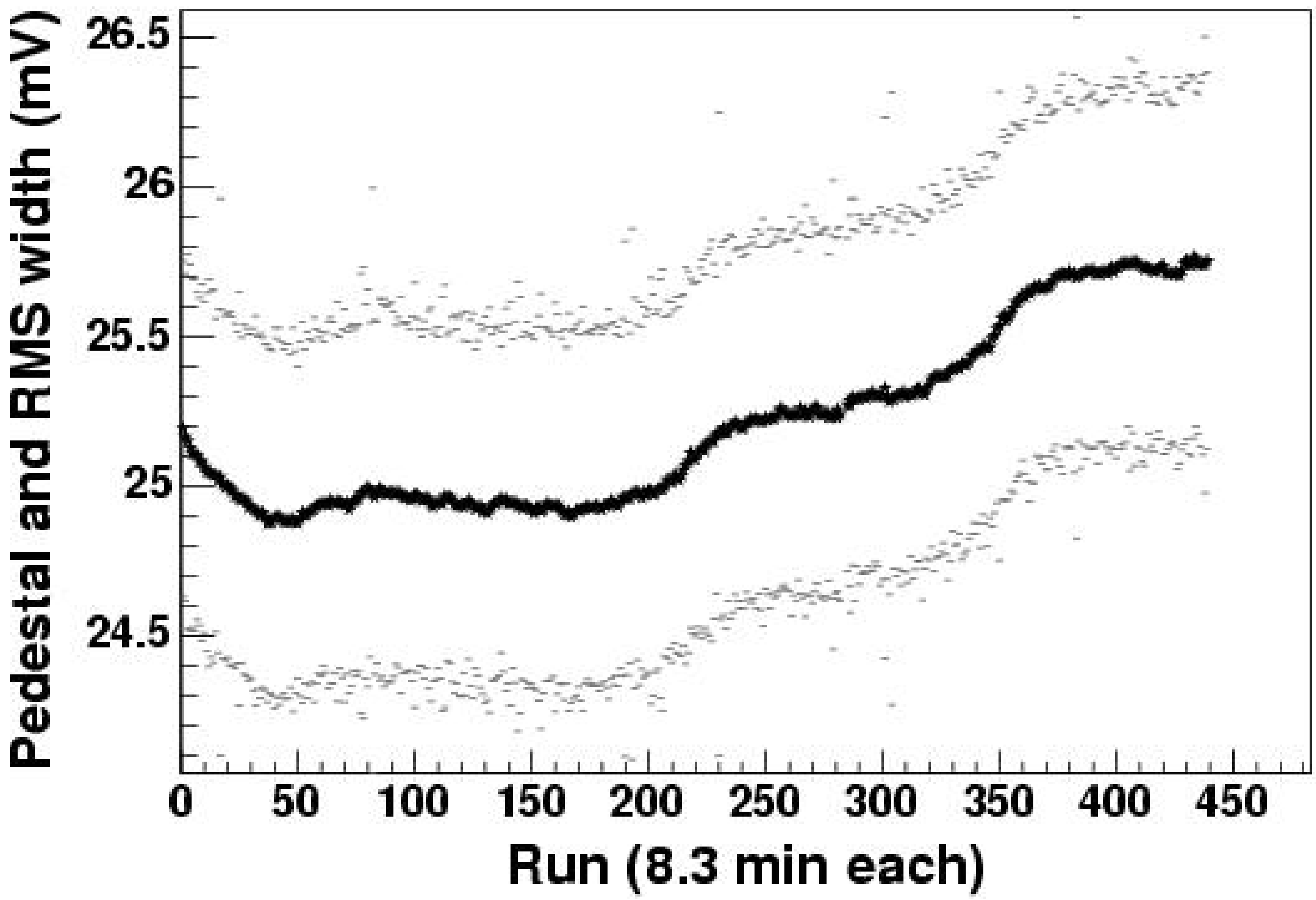
Detector Array performance

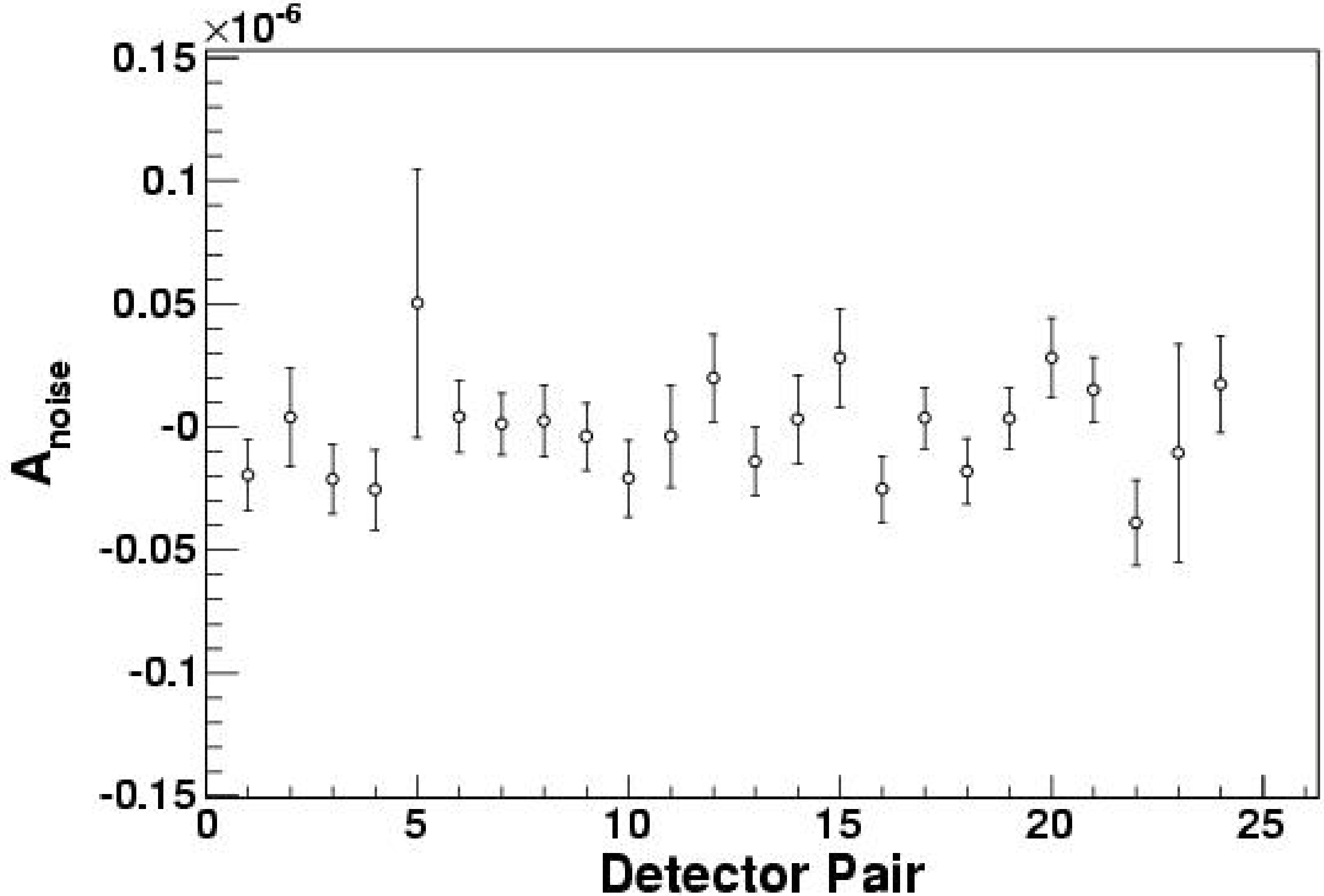
The detector preamplifier was designed to operate close to the level expected from thermal fluctuations.

The predicted total noise in the preamplifier is

$$S\left(\sqrt{i_{johnson}^{2}+i_{amp}^{2}}\right)\simeq 21\ \ fA/\sqrt{Hz}\ \Rightarrow\ \approx 0.1\ mV\quad \mathrm{RMS}$$




Pedestal and RMS width (mV)
26.5
26
25.5
25
24.5
0
50
100
150
200
250
300
350
400
450
Run (8.3 min each)



Ring 1 $\left(-12 \pm 7\right) \times 10^{-9}$

Ring 2 $\left(-1 \pm 6\right) \times 10^{-9}$

Ring 3 $\left(-7 \pm 6\right) \times 10^{-9}$

Ring 4 $\left(+6 \pm 7\right) \times 10^{-9}$

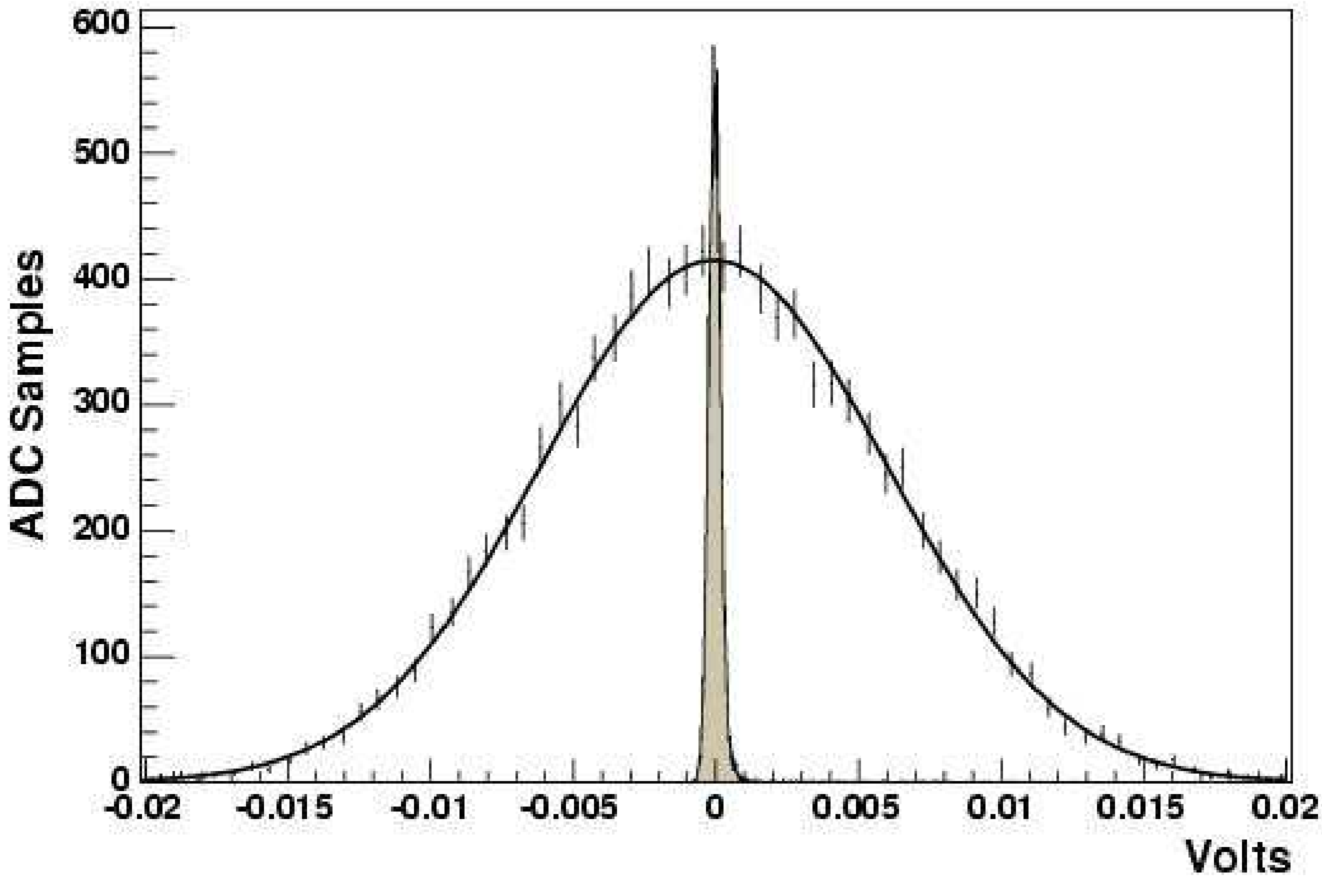
Counting Statistics

Three consecutive measurements were made.

-Three 500 sec long pedestal runs, without beam
-One 500 sec data run with beam incident on the target
-One 500 sec background run with beam but without the target installed.

The background and pedestal were subtracted and a RMS width was calculated over the run, for each time bin.

The background and noise RMS width was subtracted in quadrature.



$$\sigma_{RMS} = (6.1 \pm 0.05)\, mV$$

From Monte Carlo, expect about 8 x 10^6 n/ms/pulse at the peak or 3 x 10^4 gammas per detector. So $1/\sqrt{N} = 6\%$.

$$\sigma_{1/\sqrt{N}} = (5 \pm 1)\, mV$$